The Radiative Impact of the Radiosonde Relative Humidity Bias

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Introduction

The radiative impact of the relative humidity bias in the radiosondes launched from the Atmospheric Radiation Measurement (ARM) Cloud And Radiation Testbed (CART) central facility in 1998 has been analyzed with the Community Climate Model (CCM3) stand-alone radiation scheme. More than 800 soundings, uncorrected and corrected for the moisture bias, have been used, covering the entire year of 1998. For these preliminary calculations, the cloud cover is not taken into account. Thus, the radiative impact that we obtained can be interpreted as an upper limit. Radiative fluxes are calculated for each sounding with both the uncorrected and the corrected moisture profile. By nature, the moisture bias shows a pronounced seasonal cycle: it is weaker during the fall and winter, and increases dramatically in spring and summer. The modification of the radiative fluxes follows a similar seasonal cycle, which is strongly related to the precipitable water increase induced by the correction. Although radiative fluxes are relatively more sensitive to moisture changes in winter, the larger radiative impact is found during summer/spring. The longwave radiative flux at the surface is particularly sensitive to this correction. For the yearly average, the impact is larger than 2 W/m^2, and frequently reaches more than 5 W/m^2 during the moister months.

Nature of the Problem—Dry Bias in Vaisala RS-80 Radiosondes

Since 1994, comparisons between CART radiosondes and other CART instruments have suggested that significant batch-to-batch variations exist in the accuracy of radiosonde relative humidity measurements (Lesht 1995; Lesht and Liljegren 1996). This variation was statistically confirmed (Lesht 1997) by experiments conducted during the 1996 Water Vapor Intensive Operational Period (WVIOP) where a dry bias of greater than 5% was found in one batch of radiosondes. The discovery by ARM of a manufacturing calibration error that occurred in November 1994 pointed to the calibration process as the source of the problem. However, subsequent investigating by the manufacturer (Vaisala) working with

scientists from the National Center for Atmospheric Research (NCAR) concerned about bias in soundings made during the Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) indicates that the problem is a result of contamination of the humidity sensor during storage. This possibility was originally discounted because Vaisala performs storage drift tests as part of their normal quality control process. The problem was that these tests were conducted with sensor packages rather than with completely assembled radiosondes, which seem to be the source of the contamination. Vaisala has developed a preliminary and proprietary algorithm that can be used to estimate corrected values of relative humidity as a function of the radiosonde 'age' (the time between calibration and use).

The details of the correction algorithm are proprietary. We obtained access to the current working version of the correction algorithm by executing a nondisclosure agreement that requires us to keep the details confidential. After more testing and verification, Vaisala intends to release the results of the algorithm to its user community in the form of look-up tables. Separate corrections are required for the H-humicap sensor used in all ARM soundings and for the more common A-humicap. The correction procedure has three component factors: one that accounts for small errors in the basic humidity sensor calibration model, one that accounts for the cumulative effect of contamination of the sensor with age, and one that includes an improved representation of the humidity sensor's temperature response at saturation. Thus, for any particular datum, the correction is a function of the sensed relative humidity, the ambient temperature, and the radiosonde age. The cumulative effects of these correction factors are shown in Figure 1.

Because ARM has always tracked the radiosonde serial numbers (the serial numbers are included in the radiosonde metadata), it is possible to calculate the exact age of every radiosonde launched by ARM. Thus, we can apply the correction algorithm in a forward calculation mode with radiosonde age as an exactly known independent variable rather than having to estimate the radiosonde age or rely on an empirical scaling. It should be noted, however, that the Vaisala procedure also includes an adjustment factor that can be applied if there is an accurate reference value of surface relative humidity and temperature available. In essence, this adjustment factor scales the correction attributed to sensor contamination by the observed difference. By assuming that the difference between the radiosonde and reference values at the surface is due to contamination, the adjustment factor can be used in place of sonde age. We have chosen not to use this adjustment factor without further testing, however. We believe that ARM data provide the best source of information for independently testing the correction algorithm. Such tests are under way.

Example Application of the Correction

We apply the correction algorithm to the entire sounding and calculate both the corrected values of relative humidity for every point in the profile and the integrated precipitable water vapor (PWV) for every profile. Using data collected during 1997 at the Southern Great Plains (SGP) CART central facility as an example, Figure 2 shows the relationship between the differences in precipitable water vapor (PWV) calculated from the radiosonde and that measured by the ARM microwave radiometer (MWR). The top panel shows the radiosonde PWV for the uncorrected soundings and the bottom panel shows the PWV for the corrected soundings. Data are from the SGP CART central facility in 1997 using 1237 soundings.
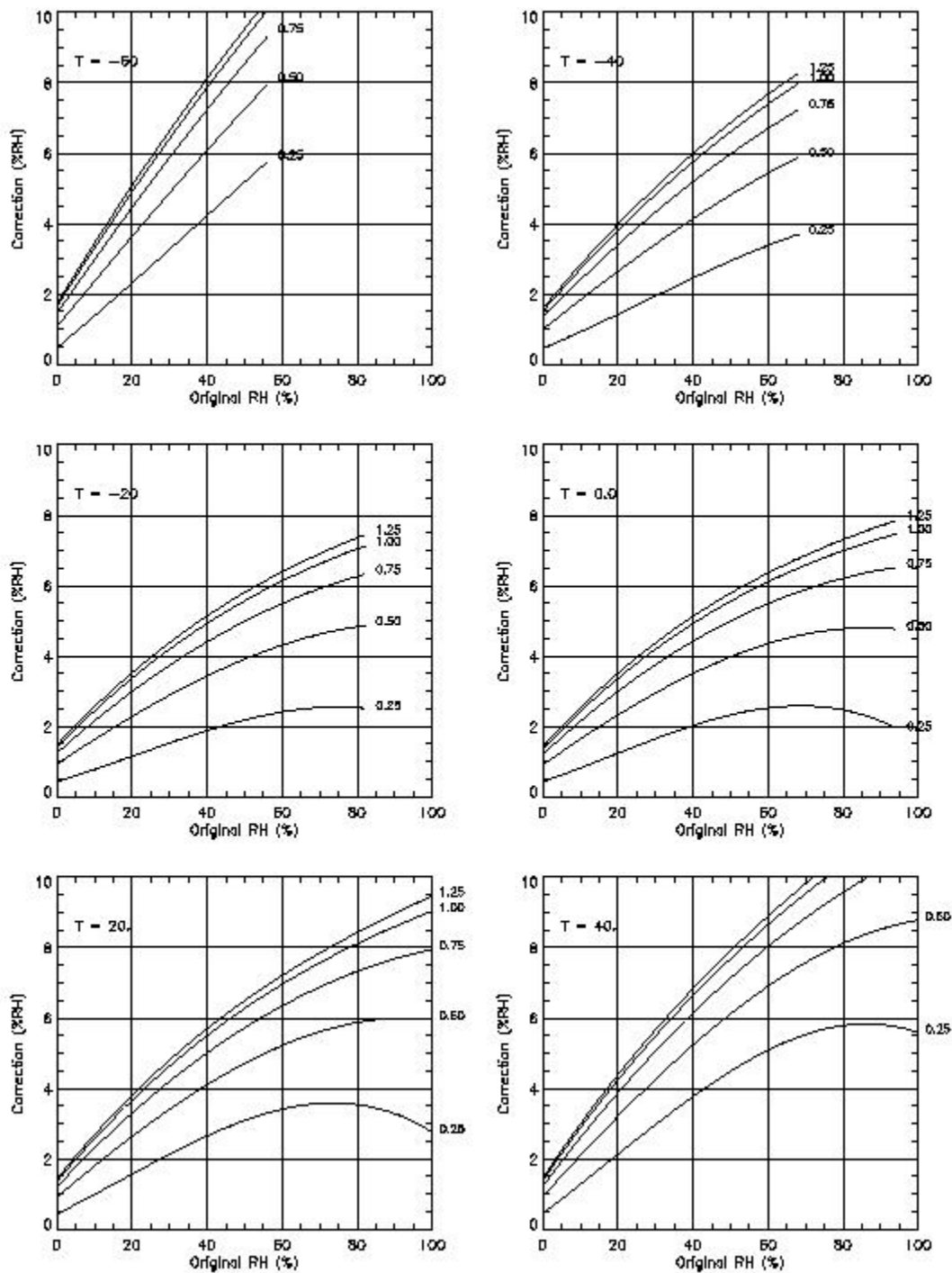
Figure 1. The total correction applied to the RS-80H humidity sensor. The total correction includes the calibration model error, the temperature sensitivity model error, and the contamination bias error. Each panel shows the correction as a function of sensed relative humidity for a different ambient temperature and for a variety of radiosonde ages (between 0.25 and 1.25 years).
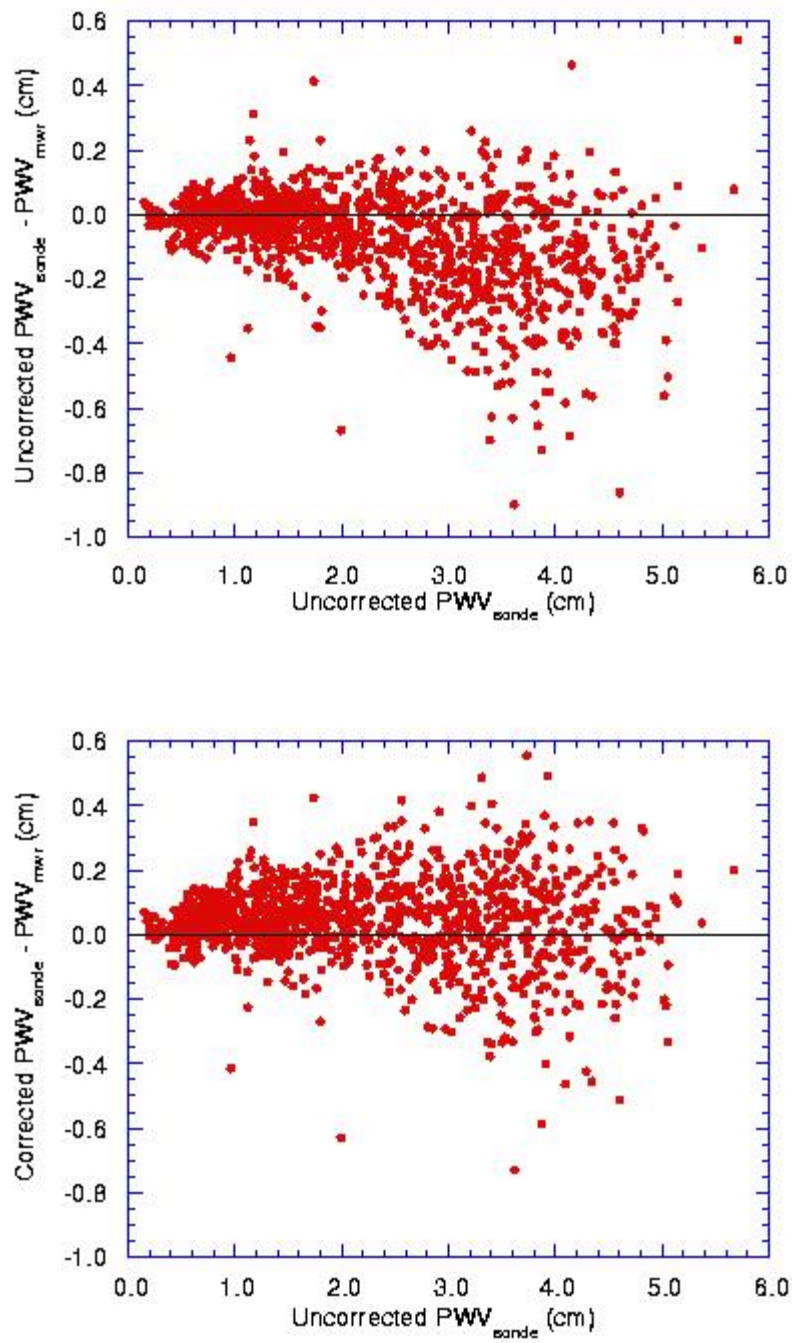
Figure 2. Differences in PWV calculated from the radiosonde and PWV measured by the ARM MWR.

Figure 2 shows how the differences between PWV calculated from the radiosonde profile and PWV measured by the CART MWR are affected by the correction. Without the correction, the radiosonde PWV is lower at higher values of PWV, in some instances drier by over 15%. Applying the correction improves the average agreement between the radiosonde and MWR PWV at high values of PWV, but appears to over-correct at lower values.

The correction does not appear to reduce the scatter in the differences at higher values of PWV. Figure 3 is a scatterplot of the corrected radiosonde PWV versus the uncorrected radiosonde PWV for soundings launched in 1997 from the SGP CART central facility. The results show that the correction increases the amount of water vapor by about 5% in a typical profile. Changes in the values of relative humidity will, of course, depend on the temperature but may exceed 10% relative humidity for older radiosondes.
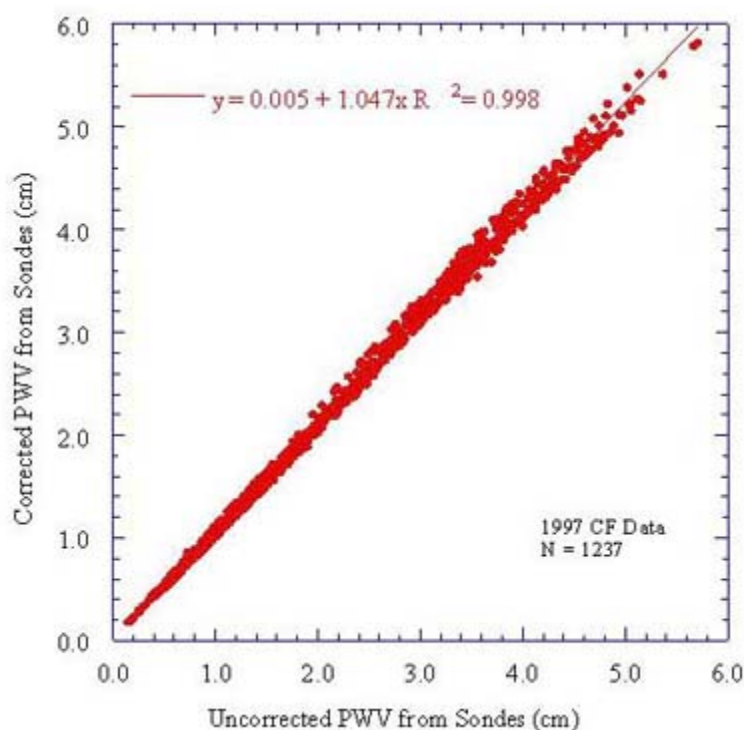

Figure 3. Scatterplot of the corrected radiosonde PWV versus the uncorrected radiosonde PWV for soundings launched in 1997 from the SGP CART central facility.

Test Dataset

The test dataset consisted of 950 out of the 1020 soundings launched from the ARM CART central facility during 1998. Those that stopped too early or with too many missing data below 100 mb were not used. Each sonde was interpolated to a uniform grid with 84 levels and the radiative calculations were then performed on an 84-level vertical grid from surface to 17315 m. Note that three additional levels above 17315 m were used in order to reach the top of the atmosphere. For these three levels, T

and q were fixed and were the same for both calculations using corrected and uncorrected relative humidity. Figure 4 shows the effects of the correction on the PWV as a function of day of year. Figure 5 shows the effects of the correction on the relative humidity and mixing ratio.
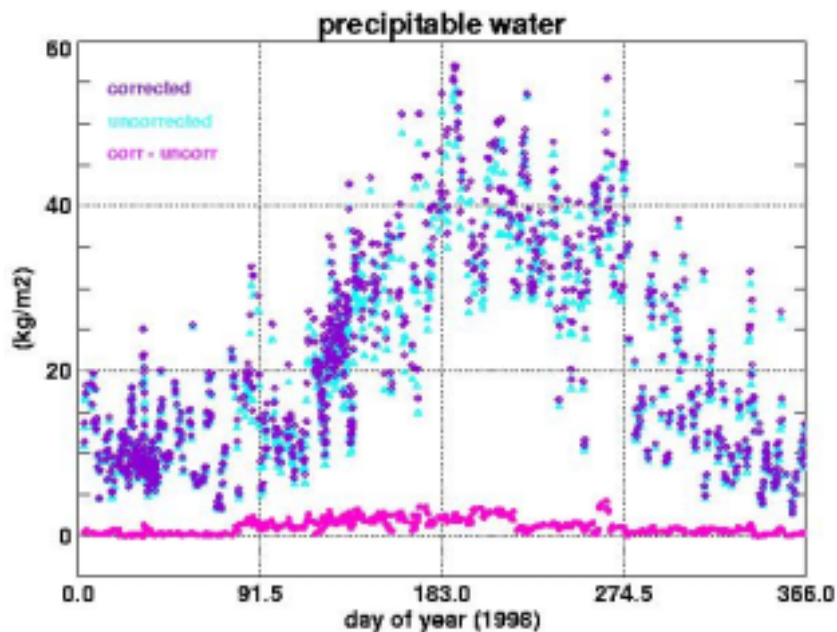
Figure 4. Seasonal variation of the moisture bias.

Radiation Model

The model used was a stand-alone version of the radiation model used in the NCAR Community Climate Model (CCM3; Kiehl et al. 1996; Kiehl et al. 1998). The longwave (LW) radiation is treated with a broadband technique and the shortwave (SW) radiation is calculated with a delta-Eddington approximation, with 18 spectral intervals (Briegleb 1992). The assumptions for the radiative calculations are:

- No clouds

- Climatological ozone profile and background aerosol was used

- Radiative effects of CO_2, N_2O, CH_4, CFC11, and CFC12 were included

- Surface temperature = Tair +1 K (crude assumption, but it did not affect the results very much)

- Surface emissivity = 0.92 (equivalent to a land-use category of agriculture and used for LW calculations)

- Surface albedo = 0.17 in the 2 SW broadbands, diffuse and direct.
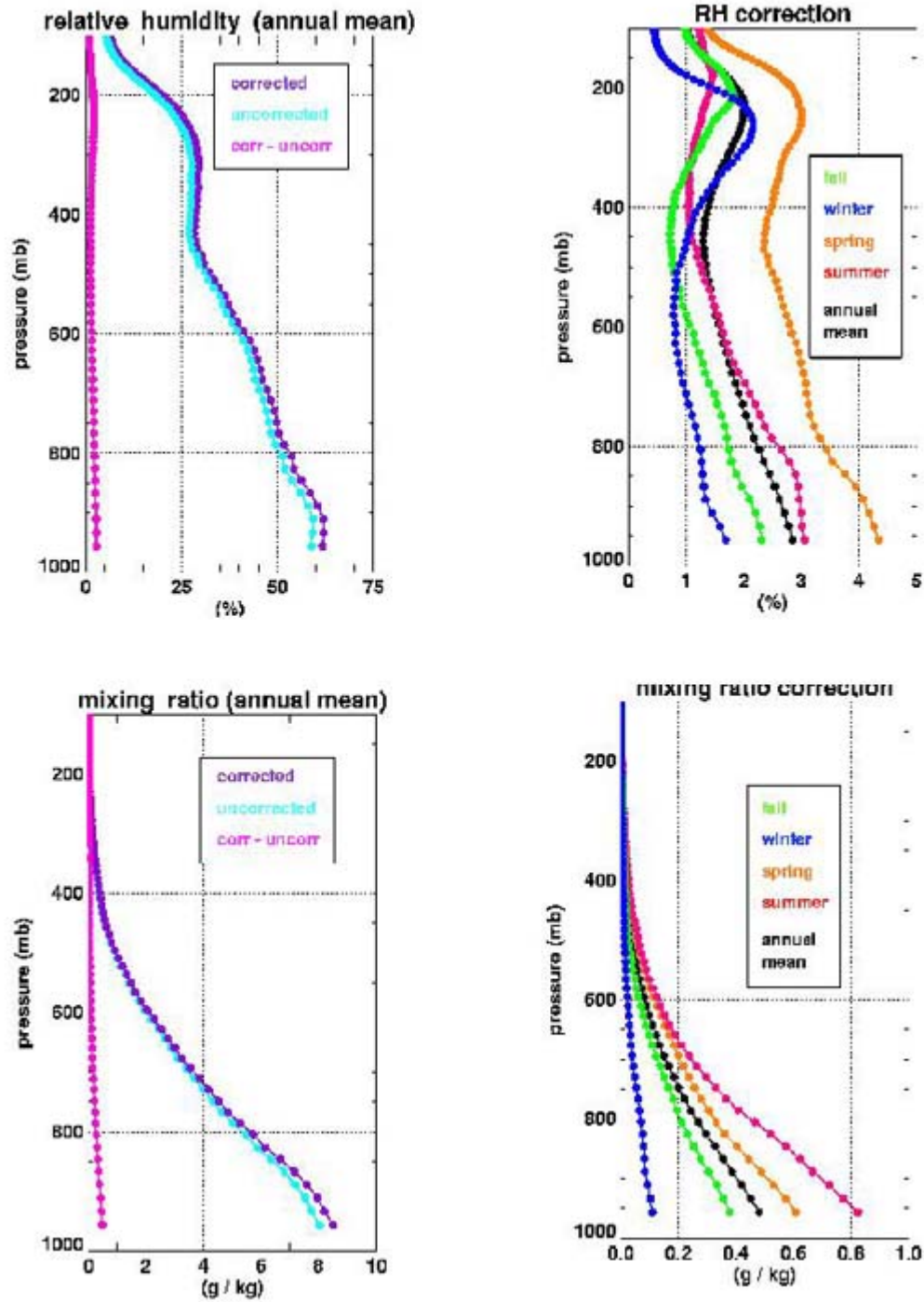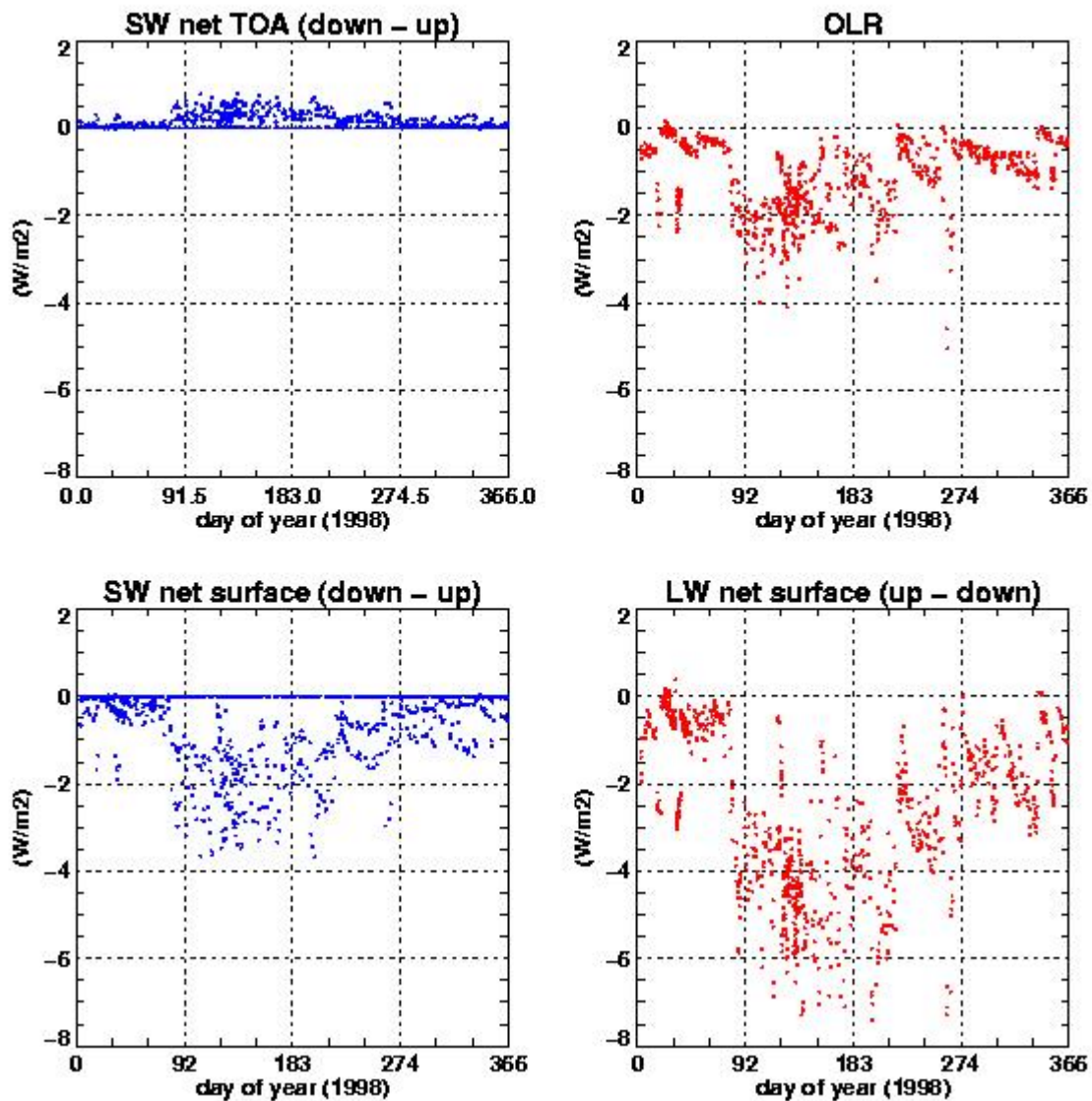
Figure 5. The effects of the sonde relative humidity correction on the relative humidity and mixing ratio.

Modeling Results

The following are key modeling results from using the NCAR CCM3 model to examine the radiative impact of the Vaisala radiosonde dry bias:

- The moisture bias shows a pronounced seasonal cycle that was weaker during the fall and winter and increases dramatically in spring and summer.

- The modification of the radiative fluxes follows a similar seasonal cycle, strongly related to the precipitable water increase induced by the correction.
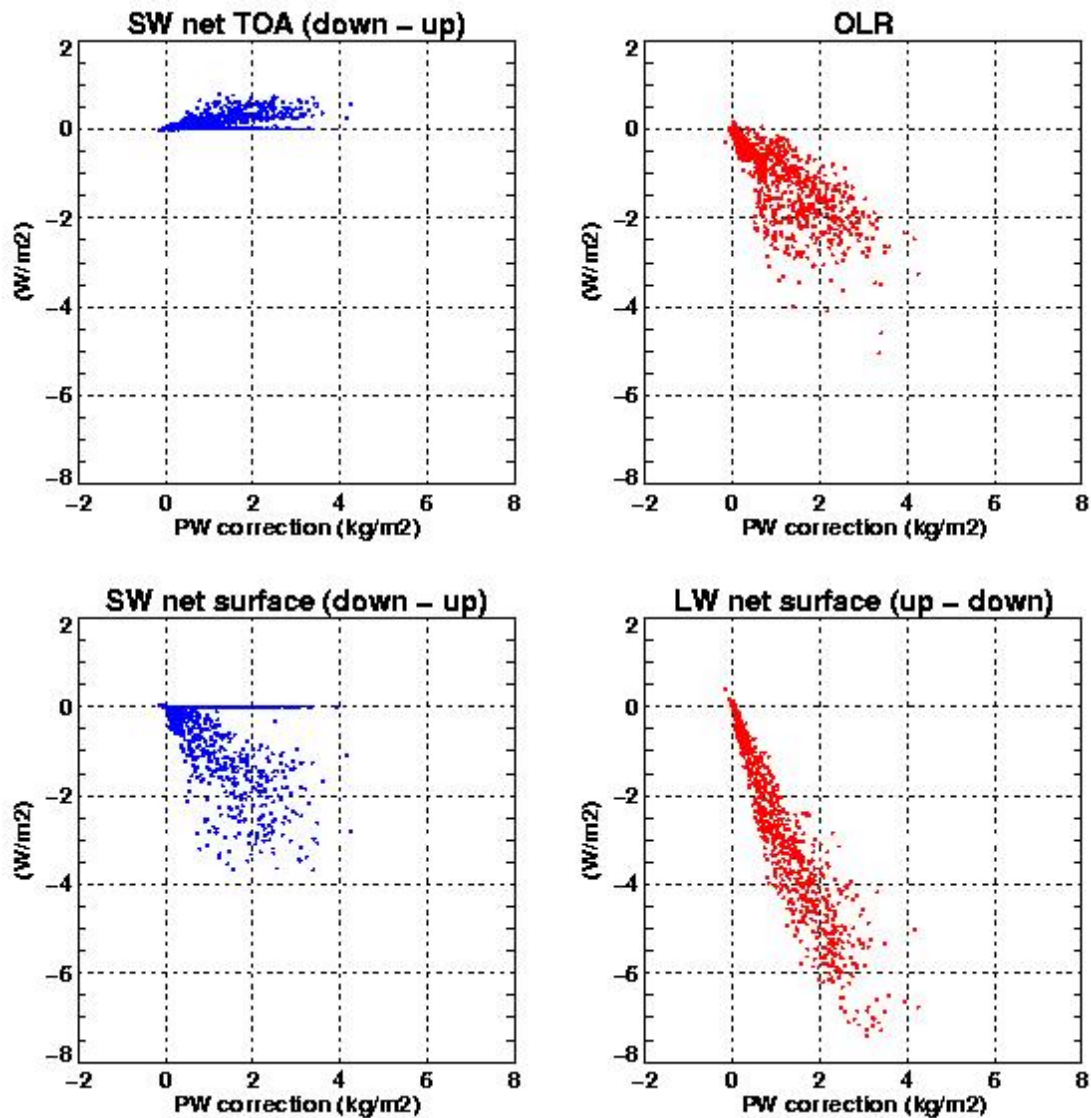

Figure 6. The effects of the sonde relative humidity correction on the modeled radiative fluxes as a function of time of year.

- Although radiative fluxes are relatively more sensitive to moisture changes in winter, the larger radiative impact is found during summer/spring.

Figure 7 shows that the longwave radiative flux at the surface is particularly sensitive to the correction. For the yearly average, the impact is larger than 2 W/m^2, and frequently reaches more than 5 W/m^2 during the moister months. Table 1 summarizes the findings, showing the radiative impact for shortwave and longwave radiation as a function of season.

Figure 7. The effects of the sonde relative humidity correction on the modeled radiative fluxes as a function of PWV.

Table 1. Summary table showing the seasonal radiative impact of the sonde dry bias.					
	Winter	**Spring**	**Summer**	**Fall**	
SW TOA (down - up)	0.0	0.1	0.2	0.1	(W/m^2)
SW Surface (down - up)	-0.2	-0.7	-1.0	-0.5	(W/m^2)
LW Surface (up - down)	-0.9	-2.6	-3.7	-2.1	(W/m^2)
LW TOA Up (= OLR)	-0.5	-1.1	-1.2	-0.8	(W/m^2)
Precipitable Water	0.3	1.4	1.8	0.9	(kg/m^2)

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